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SERVICE WEAR TEST EVALUATION OF STRUCTURAL/PROXIMITY FIREFIGHTERS GLOVES

NAVY CLOTHING AND TEXTILE RESEARCH FACILITY
NATICK, MASSACHUSETTS

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Technical Report No. NCTRF 188

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
5 JUNE 91

3. REPORT TYPE AND DATES COVERED
FINAL REPORT (1 OCT 90 - 31 MAR 91)

4. TITLE AND SUBTITLE
SERVICE WEAR TEST EVALUATION OF STRUCTURAL/PROXIMITY FIREFIGHTERS GLOVES

5. FUNDING NUMBERS
PR 62-2-58

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
NCTRF REPORT NO. 188

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NAVAL SUPPLY SYSTEMS COMMAND
CODE 04
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20376-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Navy Clothing and Textile Research Facility (NCTRF) contracted with Dynamac Corp., Rockville, Md., to develop a dual purpose firefighters glove for both crash-rescue and structural firefighting duties. This new re-designed glove eliminates the need for firefighters to maintain two distinct sets of handwear.

This report contains information relating to design characteristics of the gloves, compiled test data of user evaluations, and overall conclusions. NCTRF has recommended that this new structural/proximity glove be introduced into the supply system.

14. SUBJECT TERMS
STRUCTURAL/PROXIMITY FIREFIGHTERS GLOVES

15. NUMBER OF PAGES
34

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

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INTRODUCTION:

During FY 88, this Facility awarded a Research and Development contract to Dynamac Corporation, Rockville, MD under Contract #N00140-87-C-2015 to design and develop a new dual purpose firefighters glove for both crash-rescue and structural fire-fighting duties. Their development contract was organized in three distinct phases, as noted below:

Phase I- Design Development
Phase II- Prototype Construction and Testing
Phase III- Delivery of 75 pairs of the finished structural/proximity firefighters gloves for a user evaluation

Prior to conducting a user evaluation of the new firefighters gloves, the Air Force Engineering and Service Center (AFESC), Tyndall AFB, FL recommended that Navy Clothing and Textile Research Facility (NCTRF) and AFESC personnel travel to each of the four designated Air Force bases indicated in Table I to conduct a one day dexterity/tactility evaluation of the new gloves. Our objective was to personally observe and evaluate firefighters wearing the gloves for both structural firefighting duties and while performing egress rescue training operations on wide bodied and tactical air-craft. Of particular importance in this evaluation, was to determine the dexterity/tactility capabilities of the gloves.

During the second quarter FY 90, the new firefighters gloves were distributed to selected firefighting personnel at designated Navy, Air Force, and Marine Corps Air Stations and aboard the USS DWIGHT D. EISENHOWER, indicated in Table II, for a 90-day user evaluation. Our objective in requesting this evaluation, was to determine the comfort, fit, dexterity/tactility, durability, and overall acceptance for both crash-rescue and structural fire-fighting duties.

This report includes information relating to our overall glove evaluation, the approach and procedures used to evaluate candidate gloves, and conclusions derived from these results.

BACKGROUND:

Proximity firefighters wearing the aluminized crash-rescue ensemble (coat, trousers, hood, gloves, and boots) are often involved in drills and emergencies which bring them close to jet fuel fires and intense radiant heat. The standard aluminized glove required for crash-rescue operations is a four-finger design combining the fourth and fifth fingers (ring finger and pinky) in a single compartment. The governing specification for the glove is Mil-G-87077.

The standard aluminized proximity gloves do not provide sufficient dexterity to perform all tasks in crash-rescue operations. Firefighters must often remove their gloves to flip switches or insert pins, thereby exposing their hand or one protected by a thin liner flyers glove covered by Mil-G-81188 to crash fire hazards.

During egress rescue operations of "getting the pilot out of the aircraft", there are circumstances under which the firefighter must remove the aluminized gloves and use the Nomex simplex flyers gloves worn as liners. Latches and switches on aircraft are frequently small and hard to access with bulky gloves. Switches to shut down the engine and latches to disengage safety harnesses were not designed to be operated with heavy gloves. Firefighters are very unlikely to put their aluminized gloves on after removing them during an egress rescue operation.

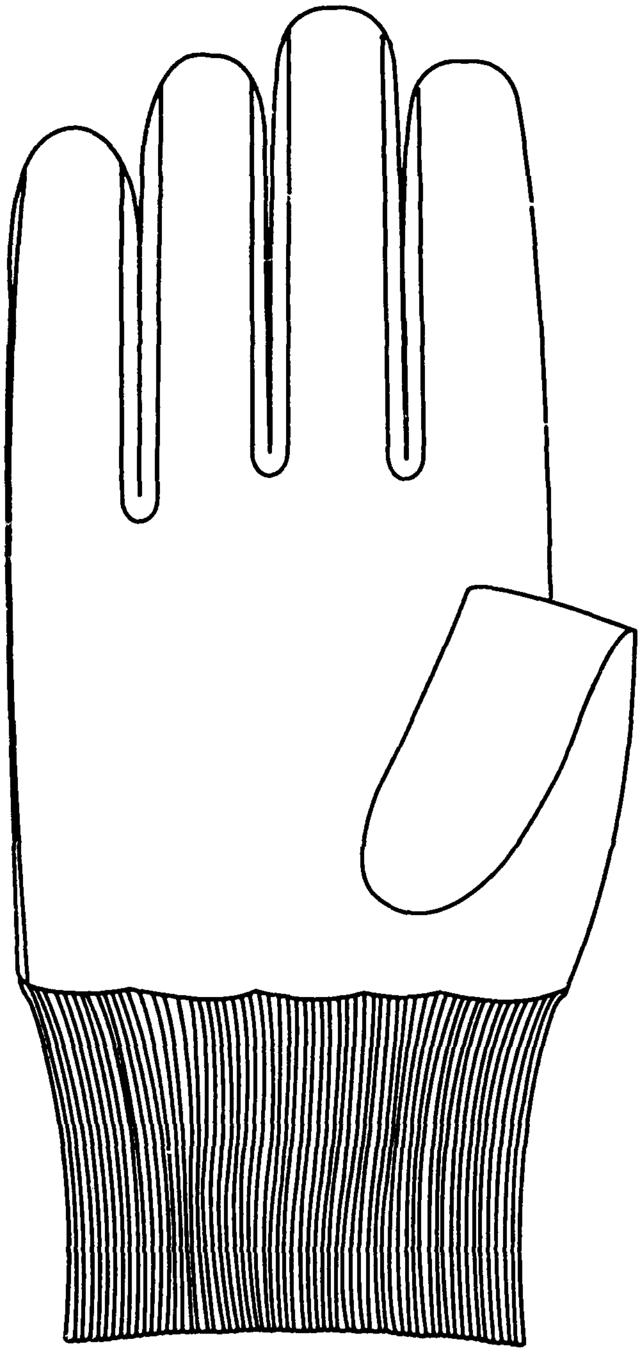
It is known that many firefighters are wearing structural firefighters gloves commerially available in lieu of the standard issue aluminized glove for crash-rescue operational duties. For these firefighters, the structural gloves are perceived to have better overall comfort and dexterity than the standard issue glove. This Facility strongly opposes the wearing of any structural firefighters glove for crash-rescue duties, particularily during egress rescue operations which can be very dangerous. It is highly questionable whether structural firefighters gloves will provide the necessary thermal protection from the radiant heat flux levels produced in crash fires.

Navy and Air Force personnel at shore stations have expressed a need for a dual purpose structural/proximity firefighters glove. At these facilities, firefighters are required to respond to both structural and crash-rescue operations. Each of these firefighting conditions require a specialized glove. In the area of hand protection for crash-rescue personnel, high levels of protection are required from radiant, conductive, and convective heat. The gloves must have sufficient dexterity for manipulation of rescue tools, aircraft latches, switches, and aircrew safety harness fasteners. Hand protection problems for structural firefighting have largely been solved.

APPROACH:

The new structural/proximity firefighters glove, as shown in Figure I, is of a 5-finger gunn-cut style with a straight thumb and knitted wristlet. The three layered glove construction consists of a double chrome tanned split cowhide leather palm, a back piece fabricated from an aluminized knit Kevlar/PBI/PFR rayon material, a liner fabricated from a knitted Kevlar/PBI/PFR rayon material, and a moisture barrier Bion II/Nylon tricot insert sandwiched between the liner and the aluminized back piece of the glove. The knitted wristlet is fabricated from Kevlar/PBI material. This new dual purpose glove meets the radiant heat protective characteristics of the current standard crash-rescue glove. The glove incorporates a breathable membrane to reduce hand sweating, and is designed to provide the necessary heat protection, durability, waterproofness, and dexterity/tactility for all applicable firefighting duties.

Dexterity/tactility glove evaluations were requested by the Air Force (AFESC), to test the new structural/proximity firefighters gloves. Table I indicates the designated Air Force base and number of firefighters requested to perform their assigned structural and/or crash-rescue duties. Six pairs of the finished gloves were requested prior to completion of contract quantity and hand carried to designated test sites.



PALM

FIGURE 1

GLOVES, FIREMEN'S, STRUCTURAL/ALUMINIZED PROXIMITY

Table I - Dexterity/Tactility Evaluation

Test Site	Location	Number of Test Participants Egress Rescue Operations	Structural Firefighting
Pope AFB	Goldsboro, N.C.	6	6
Seymour Johnson AFB	Fayetteville, N.C.	6	6
Mc Guire AFB	New Jersey	6	6
Loring AFB	Maine	6	6
Total		24	24

User evaluations were requested on the structural/proximity firefighters gloves to determine their overall acceptability by Naval, Marine Corps, and Air Force firefighting personnel. Table II indicates the designated test sites and pairs of gloves issued for a 90-day user evaluation.

Table II - Distribution of Structural/Proximity Firefighters Gloves

Test Site/ Ship	Location	Pairs of gloves Issued
Marine Corps Air Station	Cherry Point, N.C.	9
Marine Corps Air Station	Beaufort, S.C.	7
Naval Air Station	Oceana, Virgina Beach, Va.	6
Naval Air Station	No. Weymouth Mass	5
USS DWIGHT D. EISENHOWER	Norfolk, Va.	6
Eglin AFB Firefighting School	Ft Walton Beach, FL	15
Total		48

PROCEDURE:

Dexterity/Tactility Evaluation:

As shown in Table I, a total of 48 firefighters were selected from the designated Air Force bases to perform dexterity/tactility evaluations with the new structural/proximity gloves. Six each crash-rescue and structural firefighters at each test site were fitted with one pair of the new structural/proximity firefighters glove. Our objective was two-fold:

To observe and evaluate crash-rescue firefighters performing a simulated egress rescue operation on wide-bodied and tactical aircraft.

To observe and evaluate structural firefighters performing their normally assigned duties.

For our crash-rescue evaluation, a simulated and timed egress rescue evaluation was performed utilizing six firefighters donned with the standard aluminized proximity coat, nood, and gloves. The types of aircraft utilized in this evaluation were F-4 and F-15 fighter planes, a B-52 bomber, and several KC-130 transport planes.

In regard to structural firefighting, the other six firefighters were requested to perform a comparative evaluation of the new firefighters glove with their currently available structural glove while performing such duties as changing the blade on their chain saws, pulling fire hoses, operating generators, resetting fire alarms, and adjusting their firefighting equipment such as the air pack and helmet straps.

User Evaluation:

As shown in Table II, a total of 48 pairs of firefighters gloves were distributed to designated Navy and Marine Corps Air Stations, and the Air Force Firefighting School for a 90-day user evaluation. It was requested that each firefighter selected be fitted with one pair of gloves and instructed to wear the gloves as often as possible throughout the November 1989-January 1990 time frame. At the conclusion of this user evaluation, briefings were held at Naval Air Station, Oceana, VA and Eglin AFB Firefighting School, FL for their overall comments.

Questionnaire forms (Appendix A), were provided each firefighter to develop information relative to comfort, fit, durability, dexterity/tactility, and overall acceptance of the gloves.

RESULTS:

Dexterity/Tactility Evaluation:

Results of the dexterity/tactility evaluation conducted at each of the designated test site shown in Table I, are based primarily upon personal observations and debriefings of selected firefighters by NCTRF and AFESC personnel. The majority of the firefighters were in agreement that the overall comfort and dexterity of the new structural/proximity firefighters gloves were superior to the standard aluminized proximity firefighters glove. It was also felt by many of the test participants that the new firefighters gloves were more comfortable and had better dexterity than their currently used structural gloves.

In regard to performing a simulated and timed egress rescue operation on wide bodied and tactical aircraft, none of the selected firefighters had difficulty opening canopies and hatches and manipulating switches on the B-29 and KC 130 transport planes. It was agreed that these tasks can not be performed as quickly and easily with the standard aluminized glove. In regard to the F-4 and F-15 fighter planes, the new firefighters glove was not much better than the standard aluminized glove in regard to maneuving the master switch which shuts down the engine and inserting the banana clip to pin down the injection seat release. It was felt that the thumb and finger lengths were too long and bulky.

For structural firefighting, all of the selected firefighters were able to perform their required duties without difficulty.

User Evaluation:

Results of the user evaluation were based primarily upon debriefings of selected firefighters; and compiled test data at designated Naval and Marine Corps Air Stations and Eglin AFB Firefighters School. The questionnaire data from the USS DWIGHT D. EISENHOWER was not received.

Naval and Marine Corps Air Stations

Of the 27 Naval and Marine Corps firefighters issued the gloves, all of the participants responded at the end of the 90-day user evaluation. Marine Corps firefighting personnel are assigned exclusively to crash-rescue duties. Naval firefighting personnel are involved in both crash-rescue and structural firefighting duties. The major types of crash-rescue and structural duties encompassed such tasks as:

Crash rescue duties involving work on arresting gear.

Structural fire salvage and overhaul.

Down locking aircraft, firefighting training, and opening panels on aircraft.

All types of training with hoses, ladders, tools, etc.

Crash and structural, such as pinning of aircraft, pilot rescue drills, etc.

Use of all handline nozzles and rescue equipment during firefighting and rescue operations.

Overall opinion:

Marine Corps Air Station, Cherry Point, N.C.

The new structural/proximity firefighters glove met the durability, dexterity/tactility, and comfort needs required by firefighters to perform their duties.

Marine Corps Air Station, Beaufort, S.C.

Recommended that the vapor barrier liner or membrane be improved to prevent glove from retaining water.

Finger lengths of the glove should be in proportion to the human hand, in particular they are too long for egress rescue operations.

Leather palms of the gloves are too soft and porous, absorb oil and dirt too easily and very difficult to clean.

Gloves have very good dexterity/tactility compared to the standard issue firefighters glove, however, the firefighter will experience difficulties manipulating small pins (ejection seats/canopy safety) and harness fittings in the cockpit of an aircraft. NAVAIRSYSCOM should continue to authorize the use of summer flight deck nomex glove to be worn on the inside of the new firefighters glove for crash rescue firefighting.

Ease of donning:

The majority of the responses (85%), indicated that the gloves could be easily donned. The negative responses encompassed the following comments:

- The knit wristlet felt a little too tight, making it difficult to don the gloves.

- When the weather was hot and your hands got sweaty, they were difficult to don.

- Several complaints surfaced regarding the liner pulling out when the glove was doffed.

Comfort and fit:

The majority of the responses (67%), indicated the gloves fit well and were comfortable. The negative responses encompassed the following comments:

- Did not get a proper fit around each finger and fist area of the hand.

- Fingers seem to be too long.

- Gloves were too big around the fingers.

- Gloves are bulky at base of fingers making them uncomfortable.

Evidence of aluminized fabric failures on back of gloves:

Overall, the aluminized fabric on the back of the hand held up extremely well to both crash-rescue and structural firefighting duties. However, 33% of the responses reported cracking of the aluminized fabric between the fingers and base of fingers as the most prevalent problem.

Durability:

The majority of the responses (81%), indicated the gloves were durable. The negative responses encompassed the following comments:

- Excessive cracking of the aluminized fabric below finger areas on back of gloves.

- Where the aluminized fabric is sewn between the fingers on the back of the hand, cracking occurred.

- Small cracks have developed on the aluminized fabric at the back of the hand.

Egress training operations:

The majority of the responses (74%), indicated the firefighters were able to perform the egress training exercise with minimal difficulty. The negative responses encompassed the following comments:

- Personnel expressed little difficulty when it came to operating compartment hatches, however, shutdown procedures were difficult because of their bulkiness.

- Marines found the gloves too big, had to remove the gloves when it came time to pinning aircraft and downlocking.

- Small pins and latches were difficult to manipulate.

- Overall, the gloves are a big improvement over the standard issue gloves, but you still experience difficulty manipulating small pins and harness fittings in the cockpit of the aircraft.

- The fingers of the gloves are too long and the finger tips too bulky.

Favor of adoption:

The majority of the responses (81%), were in favor of adopting the new structural/proximity gloves.

Eglin AFB Firefighting School, Ft Walton Beach, FL

Fifteen pairs of the new structural/proximity firefighters glove were issued to Eglin AFB in November 1989. In their weekly training exercises, which are conducted for firefighting personnel throughout the year, the gloves were evaluated by more than 15 test subjects. A total of 79 firefighters evaluated the prototype gloves throughout the December 1989 - February 1990 timeframe. After each week of training, the 15 pairs of gloves were passed on to the next class for evaluation.

During the first training class conducted during the 3-9 December 1989 time frame, the selected firefighters reported the gloves were wetting through, and the liners were pulling out very easily when they removed their hands. After trying unsuccessfully to air dry the gloves, they put the gloves in a commercial tumble dryer (hot temperature setting) which compounded the problem. The leather dried out and made the gloves very boardy to the succeeding classes of test participants. The wear test evaluation of the gloves should have been terminated at the end of the first week. The overall comments received from Eglin AFB at the conclusion of the test period, were determined to be invalid.

DISCUSSION OF RESULTS:

User Evaluation:

Based on our debriefings of test participants at several of the designated test sites, (Naval Air Station, Oceana, VA and Eglin AFB Firefighting School, FL) along with the overall personal responses from the test questionnaires, the new dual purpose firefighters glove received an overall positive response for both crash rescue and structural firefighting duties. However, the most prevalent complaints of the gloves wetting through and the liners pulling out needed to be addressed before adoption of the gloves could be recommended.

A limited quantity of final prototype gloves were manufactured by Knoxville Glove Co., Knoxville, TN, and forwarded to the Marine Corps Air Station, Beaufort, SC for an additional 30-day evaluation. The gloves incorporated the following modifications:

The outer shell was fabricated of the standard silicone treated leather procured under Mil-L-2004 and currently used for military firefighters and damage control gloves. The inclusion of silicone treated leather was intended to reduce water absorption. The experimental wear test gloves utilized commercially available double chrome tanned leather.

The moisture barrier glove inserts were fabricated as required (heat sealing the coated sides of the fabric together). A NCTRF representative visited the subcontractor (Emtex Inc., Chelsea, MA) during a subsequent inspection of the finished inserts, and participated in their verification testing of the inserts for pinhole leaks. The inserts easily passed water resistance requirements. As indicated in Dynamac Corporation final report, Emtex Inc. revised their initial manufacturing procedure (phase I inserts) for ease of production, resulting in poor heat sealed seams and leakage around the fingers.

The liners of the gloves were reversed (smooth side of fabric face side up) for improved ease of donning and doffing the gloves. The experimental gloves were made with the napped side of the fabric face side up, which compounded the problem of the liners pulling out when the gloves wet through. In addition, a new silicone adhesive was used to fasten the fingertips of the lining to the insert for improved bond strength.

At the conclusion of the 30-day wear test evaluation, the Marine Corps' Air Station reported extremely favorable comments with no evidence of the gloves wetting through or the liners pulling out. The Marine Corps recommended that the gloves be introduced into the supply system as soon as possible.

CONCLUSION:

This new dual purpose structural/proximity firefighters glove couples advanced state of the art fabrication technology along with moisture barrier and high performance fire retardant materials necessary to achieve the protection and performance needs of the DOD firefighting community. Based on overall positive responses from the test participants involved in this 90-day user evaluation, along with conclusive design and material development data furnished in Dynamac Corp Final Report dated 31 December 1989 (Appendix B), this glove meets the radiant heat protective characteristics of the current crash rescue glove and the National Fire Protection Association (NFPA) standards for structural handwear.

RECOMMENDATION:

Because of the urgent need for this glove by the firefighting community, it was the recommendation of this Facility that this program not be transitioned to 6.3 advanced development and that the new structural/proximity firefighters glove be introduced into the supply system. The supply request package was forwarded to DPSC on 15 January 1991.

APPENDIX A

NAME/RATE: --

STATION: --

SIZE OF GLOVES ISSUED: --

EVALUATION DATE: START ------------ FINISH ------------

1. For Crash-Rescue firefighting, please furnish the following information on the gloves you are currently using:

   Standard issue (Stock No.) -------------------------------
   or

   Commercial type (Manufacturer's Name and Style No.)

   ----

2. For Structural firefighting, please furnish the following information on the gloves you are currently using:

   Standard issue (Stock No.) --------------------------------
   or

   Commercial type (Manufacturer's Name and Style No.)

   ----

3. Were the experimental gloves worn in both crash-rescue and structural firefighting duties ?

   Yes ------------ No --------------

   If No, please indicate which firefighting mode (crash-rescue and structural the gloves were worn.

   ----

4. Approximate the percent (%) wear time the experimental gloves were worn in the crash-rescue and structural firefighting modes.

   Crash-rescue duties --------------------------------

   Structural duties --------------------------------

5. Briefly describe the major types of duties that were performed while wearing the experimental gloves:

Crash-rescue ---

Structural duties --

----

6. Did the experimental gloves fit properly ?

Yes ---------------   No ---------------

If No, please explain --

----

7. Did the experimental gloves in any way hamper your abilities to perform your assigned duties ?

Yes --------------   No ----------------

If yes, please explain ---

----

8. In terms of durability, did the experimental gloves show excessive wear in any area, seam failure, rip or tear in the material, etc.

Yes -------------------   No -----------------

If yes, please explain ---

----

9. Did the aluminized fabric on back of the experimental gloves show any of the following surface or fabric failures ?

Cracking No ------------ Yes (location) ---------

Flaking or peeling No ------------ Yes (location) -----------

Delamination No -------------- Yes (location) ------------

10. Would you be in favor of the Navy adopting the experimental gloves in lieu of the standard or commercial type gloves you are presently using ?

Yes ----------------- No ------------------

If No, please explain --

----

11. List any comment both positive or negative on the experimental gloves worn

----

Signature -------------------

Date: -----------------------

APPENDIX B

Technical Report

DEVELOPMENT OF STRUCTURAL/CRASH FIREFIGHTERS GLOVES

Final Report
Contract No. N00140-87-C-2015
December 31, 1989

Submitted to:
Navy Clothing and Textile Research Facility
Attn: Mr. Harry Winer
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Submitted by:
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I. INTRODUCTION

A. Background.

Military firefighters are required to respond to two major types of emergencies: structural fires and crash fire/rescue (CFR). Structural firefighting is performed inside enclosed areas such as buildings or ship compartments, while CFR is generally performed outdoors or on flight decks. Conditions for these activities differ markedly. Structural firefighting has been characterized by the United States Fire Administration as presenting heat fluxes on the order of 2.0 cal/cm^2/sec, where radiant and convective fluxes each contribute 50% of the total flux (Project FIRES Volume 2: Protective Ensemble Performance Standards, Grumman Aerospace Corporation, December 1978). CFR activities generally involve burning fuels such as gasoline, kerosene, JP-4, or JP-5, and present a higher radiant flux of 1.9 cal/cm^2/sec, with a convective flux equivalent to structural levels, i.e. 1.0 cal/cm^2/sec (Firefighter's Exposure Study, Cornell University, December 1970).

Structural firefighting requirements were first identified in a report prepared for the National Institute for Occupational Safety and Health (NIOSH); this report suggested thermal and traumatic protection performance and dexterity requirements (Development of Criteria for Firefighter's Gloves, Arthur D. Little, Inc., February 1976). The U.S Occupational Safety and Health Administration (OSHA) utilized the NIOSH requirements in promulgating hand protection requirements for structural firefighters in 1980 (title 29 CFR 1910.156, Subpart L: Fire Brigades). These requirements are mandatory for all structural firefighters employed by the federal government. In 1983, the National Fire Protection Association (NFPA) utilized the NIOSH research to promulgate NFPA 1973-1983 edition, Gloves for Structural Firefighters. NFPA 1973 requirements were similar to OSHA's, with the addition of a waterproofness requirement. Several states and many fire departments have voluntarily adopted NFPA 1973. Injury statistics have now demonstrated that gloves meeting these requirements are providing adequate protection for the structural firefighting environment (Annual Death and Injury Survey, International Association of Firefighters, 1980-1987).

While hand protection problems for structural firefighting have largely been solved, little work has been done in the area of hand protection for CFR firefighting, although an NFPA subcommittee is currently addressing the subject. CFR requires both high levels of protection from radiant and convective heat, as well as fine dexterity for manipulation of rescue tools, aircraft latches, fittings, switches, and aircrew safety harness fasteners. The Federal Aviation Administration (FAA) has issued general guidelines for CFR protective clothing (Airport Fire and Rescue Personnel Protective Clothing, Federal Aviation Administration, March 1986), but no specific requirements for CFR gloves were included. This circular notes that since no currently available gloves adequately meet both thermal protection and dexterity requirements, structural and CFR gloves should be carried and utilized at the firefighter's discretion,

or CFR gloves should have removable liners that can be used without the shells when greater dexterity is required.

In practice, however, firefighters surveyed indicate that great difficulties are encountered with current CFR gloves in field usage (personal communication, CFR firefighters at Hanscom and Andrews Air Force bases and Dulles Airport; and telephone communication, firefighters at Oceana Naval Air Station and Cherry Point Marine Corps Air Station: March and April 1988; Report on Firefighter's Gloves, Navy Clothing and Textile Research Facility, February 1987). In particular, most firefighters wore various commercial structural firefighting gloves for both structural and CFP operations, noting that the increased dexterity was required for efficient operation, particularly in extricating pilots and aircrews from aircraft. It was also noted that the structural gloves did not provide adequate protection from high radiant heat condition characteristic of aircraft fuel fires.

Of the commercial gloves utilized, Western Firecraft Project FIRES gloves utilizing a chrome-tanned split cowhide shell, Goretex waterproof insert, and modacrylic knit liner (Project FIRES Final Report, International Association of Firefighters, 1986), were often judged to afford adequate dexterity for both structural and CFR applications. This opinion was shared by many of the municipal fire department surveyed, including Boston, New York, Chicago, Seattle, Dade County, and Arlington, Virginia (telephone and personal communications, March 1988). Firefighters utilizing military issue 5-finger unlined and 4-finger lined aluminized gloves wore lightweight aircrew Nomex/capeskin gloves or previously issued Kynol inserts as liners, and doffed the aluminized shells when dexterity was required. When aluminized shells were worn, rescue tools such as crash axes and pry bars could not be manipulated, and in particular, pilots could not be quickly extricated from aircraft due to glove stiffness. It was noted that in practice, after the shells were removed, they were usually not replaced, and hand injuries such as lacerations, burns and frostbite were relatively common during rescue operations.

Because of these factors, the Navy Clothing and Textile Research Facility (NCTRF) issued a request for proposal (RFP) Research and Development of Structural/Crash Firefighting Gloves in June 1987. The RFP required the design, testing, and prototype production of a glove that would meet structural firefighting requirements as specified in NFPA 1973-1983 and provide protection from burn when the back was exposed to a radiant flux of 1.9 cal/cm^2/sec for 30 seconds. A contract was awarded to perform the work specified in the RFP in October 1987 to a team consisting of Dynamac Corporation, Arthur D. Little, Inc., and Knoxville Glove, Inc.. The program was to be conducted in three phases: 1) Design Development, 2) Prototype Construction and Testing, and 3) Delivery (pattern and glove production).

B. Kick-Off Meeting.

A Kick-Off meeting for the program was held at NCTRF on October 29, 1987. Representatives from NCTRF, Dynamac Corporation, and Arthur D. Little, Inc. were present. At this meeting, Dynamac Program Manager Jack Sawicki noted

that the NFPA subcommittee on structural firefighting gloves was currently revising NFPA 1973-1983, and planned to release NFPA 1973-1988 in Spring 1988. The published preliminary draft (Technical Committee Report for NFPA Annual Meeting, NFPA, August 1987) had:

1) changed flame resistance test procedure and substituted a Meket burner fueled with butane for a Bunsen fueled with methane;

2) added a Thermal Protective Performance (TPP) rating of 35 with a 2.0 cal/cm^2/sec 50/50% radiant/convective heat flux on a Custom Scientific Instrument (CSI) TPP apparatus (Structural Firefighters Protective Clothing, NFPA Standard 1971-1986) for both palm and back of glove;

3) and, substituted a 500°F hotplate for the contact heat test ASTM F-1060 (Thermal Protective Performance of Material for Protective Clothing for Surface Contract).

Discussion regarding performance or testing of materials for compliance with the 30 second exposure to a radiant flux of 1.9 cal/cm^2/sec resulted in a decision to utilize the CSI TPP tester to determine the time to burn index (TBI) based on the Stoll Curve (Thermal Protection Capacity of Aviator's Textiles, Naval Air Development Center, May 1961), and the NCTRF Quality Control (QC) apparatus (Development and Evaluation of an Infrared Radiant Heat Test Apparatus for Firefighter's Aluminized Proximity Fabrics, Naval Supply Research and Development Facility, date of publication unknown; and Validation of Heat Flux for Standard Quartz Lamp Tester and Calibration of NCTRF Heat Flux Transducer, Naval Air Development Center, March 1980) for evaluating effectiveness and durability of aluminized fabric.

II. METHODS AND RESULTS

A. Preliminary Fabric Selection.

Preliminary fabric selection was made for all glove components as follows:

Shell, glove back, aluminized with Gentex (G) or 3M processes*:

5.0 oz/yd^2 polybenzimadazole (PBI/Kevlar) knit (G)
8.0 oz/yd^2 PBI/Kevlar/Durvil rayon knit (3M)
8.0 oz/yd^2 Kevlar brushed knit (3m)

*** The Gentex process fabric was commercially available; 3M process fabrics were aluminized by Knoxville Glove, Inc..**

Moisture barrier:

Goretex microporous polytetrafluorethylene (PTFE)
Bion II semipermeable urethane file/nylon Tricot

Lining:

8.0 oz/yd^2 woven wool
8.0 oz/yd^2 PBI/Kevlar/Durvil knit

Wristlet:

6.0 oz/yd^2 Kevlar circular knit
6.0 oz/yd^2 PBI/Kevlar circular knit

Palm:

Chrome-tanned split cowhide, 2.5, 3.0, 3.5, and 4.0oz/ft^2

B. **Radiant Heat Resistance Testing.**

Four layups were tested for radiant heat resistance on the Hoescht/Celanese CSI TPP apparatus located in the PBI laboratory in Charlotte, NC. The apparatus sample holder was modified to allow exposure to a 1.8-1.9 cal/cm^2/sec radiant flux. Results are listed in Table I. The only layup meeting the NCTRF 30-second TBI requirement was Sample A, consisting of 5.0 oz/yd^2 PBI/Kevlar knit, aluminized by the Gentex process, which had a TBI of 36.0 seconds. Neither of the 3M process samples met this requirement, even though both Sample C and Sample D were 3.0 oz/yd^2 heavier than Sample A; inspection of the samples showed severe deterioration of the 3M aluminized coating. From these results, it was inferred that the 3M process may not be suitable for use in the CFR gloves. It is interesting to note that Sample B, identical to Sample A, except for the deletion of the 1.0 oz/yd^2 Goretex film, had a TBI of 27.0 seconds, 9.0 seconds less than Sample A.

After tests for radiant heat resistance, three fabrics were exposed to a radiant flux of 1.9 cal/cm$_2$/sec on the NCTRF Quality Control Radiant Heal apparatus. Results are found in Table II. The only fabric that met MCTRF requirements of 30 seconds exposure was the PBI/Kevlar aluminized by the Gentex process. From these results, it was concluded that the 3M process should not be utilized for glove shells.

Examination of the samples from the two tests described above, indicated that the actual exposure on the CSI apparatus was significantly more severe than on the NCTRF QC apparatus, even though both were calibrated to the same radiant flux. From observation of the testing, it appeared that a probable explanation to this aberration was the difference in positioning of the samples relative to the quartz lamp heat sources of the two apparatus. While both apparatus orient the sample parallel to the quartz lamps, the NCTRF QC apparatus lamps are

vertical, while the CSI apparatus quartz lamps are horizontal, placing the sample directly above the heat source. It appears that convective heat produced by the lamps escapes without impinging upon the sample in the NCTRF QC apparatus; in the CSI apparatus, the convective heat impinges on the sample, causing first discoloration and then severe charring of the aluminized coating. From these results, it was concluded that the CSI TPP apparatus is unsuitable for use in evaluating radiant heat flux exposures.

For this reason, it was decided to utilize another device developed by NCTRF, the Crash Fire Simulator, to determine radiant heat resistance. This device is similar in concept to the CSI apparatus in that it consists of a bank of quartz lamps as a radiant heat source, shutter, sample holder, and a skin simulant temperature measuring device. However, on the Crash Fire Simulator, both the heat source and the samples are oriented vertically, allowing convective heat from the quartz lamps to escape without impinging on the sample. From inspection of Crash Fire Simulator data previously gathered by NCTRF (Firefighters Structural/Crash Gloves, NCTRF, February 1987), it was noted that a composite as light as a 4.0 oz/yd^2 Kevlar shell (aluminized by the Gentex process); PTFE moisture barrier; and 8.0 oz/yd^2 PBI/Kevlar/Durvil liner, yielded a TBI of 41.7 seconds when exposed to a 1.9 cal/cm^2/sec radiant flux. This exceeds the 30 second TBI required by NCTRF. From this, it was concluded that composites with Gentex aluminized shells utilizing similar weight fabrics should meet NCTRF radiant heat protection requirements.

Because previous experience has shown that three layer composites should weigh at least 16 oz/yd^2 to yield a TPP of 35 when exposed to a 2.0 cal/cm^2/sec 50/50% radiant/convective flux, 8.0 oz/yd^2 Kevlar and 8.0 oz/yd^2 PBI/Kevlar/Durvil knit was procured and sent to Gentex for aluminizing.

C. Glove Prototype Construction and Testing.

TPP testing of composites utilizing these shell fabrics was performed at Hoescht/Celanese. These results are found in Table III. It is evident from Table III that the only composite meeting TPP requirements consisted of the aluminized 8.0 oz/yd^2 (before coating) Kevlar shell, Goretex moisture barrier, with 9.0 oz/yd^2 Kevlar lining. A glove prototype was constructed with these materials; it was obvious from inspection that gloves made with these fabrics could not meet the dexterity requirements of NFPA 1973. Another glove prototype was constructed with the aluminized PBI/Kevlar/Durvil shell, Goretex constructed with these materials allowed good dexterity, and would meet standard dexterity requirements, but not thermal protection requirements.

Glove moisture barrier inserts constructed of Bion II/nylon Tricot were then substituted for Goretex in a test composite, with the Gentex aluminized 8.0 oz/yd^2 PBI/Kevlar/Durvil shell and a 8.0 oz/yd^2 PBI/Kevlar/Durvil liner. Repeated TPP testing at Hoescht Celanese yielded an average result of 42.4, thus meeting the 35 requirement.

Leather splits were evaluated to determine the lightest weight skin compatible with sewing with Kevlar thread. Examination of various sewing samples utilizing all required seams indicated that the lightest weight split cowhide that could be reliably utilized was 3.0 oz/ft^2.

A palm sample composite consisting of 3.0 oz/ft^2 leather, Bion II/nylon Tricot, and 8.0 oz/yd^2 PBI/Kevlar/Durvil was tested at 2.0 $cal/cm^2/sec$ 50/50% radiant/conductive flux on a CSI apparatus at Hoescht Celanese. A TPP of 49.6 was recorded, exceeding the 35 requirement.

The same composite was then tested on the NCTRF Crash Fire Simulator at a radiant flux of 1.9 cal/cm^2. A TBI in excess of 60 seconds resulted, thus also exceeding the 30 second NCTRF requirement.

Fabric composites of the materials discussed above were tested at Hoescht Celanese for flame resistance in accordance with the published draft of NFPA 1973-1988 (Technical Committee Documentation for 1988 NFPA Spring Meeting, NFPA, December 1987). NFPA did not accept the suggestion made to remove the afterglow requirement, but did relax it from 4.0 seconds to 8.0 seconds, possibly to allow the use of 100% Kevlar wristlets. Using the Meker burner with butane fuel, Gentex aluminized 8.0 oz/yd^2 PBI/Kevlar/Durvil had an average char length of 0.9 inch, no measurable afterflame, afterglow of 9.0 seconds, and percent consumed of 4.9%. Careful observation indicated that the afterglow and percent consumed values were due entirely to consumption of the Mylar polyester film inherent to the Gentex "dual mirror" process; the base fabric was not degraded after the burner flame was removed.

Gloves and fabric composites using these materials were produced and forwarded to Arthur D. Little, Inc. for testing for Conductive Heat Resistance in accordance with NFPA 1973-1988, and Heat Resistance, Flame Resistance, Water Penetration, Cut Resistance, Puncture Resistance, Dexterity and Grip, in accordance with NFPA 1973-1983 (NFPA 1973-1988 had not been released as scheduled due to a challenge to the standard).

Conductive heat resistance was measured using a calibrated hotplate as specified in the referenced ASTM F-1062. Average time to pain (TTP) with a 536°F source was 20.0 seconds dry and 10.0 seconds wet (requirement is >6 seconds); TBI exceeded 30 seconds dry and 20 seconds wet (requirement is >10 seconds).

Puncture resistance was measured for both dry and wet leather using a Model 112 Instron. Average results were 37.7 pounds dry; 26.5 pounds wet, compared to a required minimum of 13.2 pounds.

Cut resistance was 20 pounds for both palm leather and back fabric, dry and wet. The aluminized film was penetrated at 4-6 pounds, but the fabric resisted cut-through. Required minimum was 18 pounds.

Water resistance of the Bion II bladder was in excess of 8 psi; required minimum was 4.0 psi.

Heat resistance results were not as expected. While the fabric back of the glove easily met the 5% maximum shrinkage requirement, measuring 2% and 0% for length and width, the leather palm side shrinkage was 18% and 17% for length and width.

Grip testing also provided unexpected results. Results are found in Table IV; (80% of bare-handed performance is required). Variation is noted between subjects in all three conditions; dry/dry; dry/wet; and wet/wet. Failure was noted for two subjects in the dry/dry test.

Because of these unexpected results, additional samples were sent to Biotherm, Inc. for Grip and Heat Resistance testing. Procedures were in accordance with NFPA 1973-1988, which was finally released (NFPA 1973-1988, Gloves for Structural Firefighting, NFPA, September 1988). Heat resistance testing by Biotherm resulted in glove palm (leather) shrinkage of no shrinkage in length and 4.7% in width, and no shrinkage of glove back (requirement is <5%). Grip testing by Biotherm of dry glove with dry rope yielded no degradation; a 65 pound barehand control and 65 pound gloved-hand result (requirement is 80% or more). The barehand result is very close to the values recorded by Arthur D. Little, Inc. for all three subjects; however, extreme variation is noted with two of the three test subjects for gloved results.

III. PHASE II. METHODS AND RESULTS

To examine some of the variability noted in test results and the "feel" of the gloves produced in Phase I, materials were reinvestigated, additional samples of gloves were constructed, and tests that were deemed suspect were reexamined for possibilities of error.

A. Leather

Firefighter gloves constructed from various hides were evaluated for the actual weights of leather utilized for various parts. Measurements of leather samples were made at ADL (using an Ames 482 micrometer in accordance with FED-STD-311 Method 1011), showed a wide variation in weight. Phone interiews with tanners determined that some areas of skins, such as shoulders and heads, as well as middles, were often more inconsistent than other areas. It was also determined that the hides utilized in the Phase I gloves did not have the highest available shrinkage resistance. For these reasons the decision was made to tighten the specifications for leather in order to obtain a better product inspite of the associated increase in cost. Thus, it was decided to utilize skins meeting the requirements of FED-SPEC-KK-L-2004, Type VIII, but requiring a higher shrinkage temperature of 105°C.

Samples evaluated in Phase I for suitability for stitching were also remeasured. It was determined that samples specified as 3.0 oz/ft^2 actually measured 2.5 oz/ft^2. This was within the normal tolerance allowed by FED-SPEC-KK-L-2004, i.e. ± 0.5 oz/ft^2. Specifying a 3.0 oz/ft^2 skin will allow the maximum dexterity, a critical requirement for crash firefighting.

Discussions were also conducted regarding the variation problems encountered in Phase I with Grip Testing. It was postulated that excess amounts of water could be absorbed by the leather, used in Phase I, due to a lack of a water repellant treatment. A water repellency requirement was added to the specification to preclude variable water absorption by the leather. When tested in accordance with FED-STD-311 Method 8111, a level of 30% or less after a 30 minute immersion is acceptable. This can be obtained by use of a one-step silicone treatment process. While it is believed that this treatment is adequate, it is possible that other treatments, such as a two-part fluorocarbon process, might produce more durable results. However, it was noted that firefighters generally clean silicone-treated leather gloves with liquid Woolite soap, and it was not known whether this cleaning procedure would poison the two-step process water repellant. Thus, it was decided to specify the use of the silicone process. This is an area where future investigation is warranted.

B. Liner

To allow for production of PBI/para-aramid/PFR rayon liner material by a more economical method than raschel knitting, gloves were produced with a napped circular knit 3-end fleece supplied by Hoescht-Celanese. The fabric supplied, weighing 9.0 ox/yd^2, was too thick to produce gloves with the desired dexterity. Hoescht-Celanese was asked to produce a similar fabric, but weighing 8.0 oz/yd^2, with a thinner nap and flexibility similar to the circular knit. Hoescht-Celanese was able to supply this fabric and it appeared acceptable in weight, thickness and flexibility. Thus the decision was made to allow this variation in the specification, as an option to the supplier, providing the dexterity requirements of NFPA 1971-1988 can be maintained.

C. Glove Construction and Testing

Additional gloves, including 75 pairs for Navy field tests, as well as sufficient samples for testing in accordance with NFPA 1973-1988, were produced at Knoxville Glove, Inc. using 3.0 $\pm$ 0.5 oz/yd^2 silicone-treated cowhide and raschel knit 8.0 $\pm$ 0.5 oz/yd^2 40% para-aramid/25% PBI/25% PFR rayon shells aluminized by the Gentex process, Bion II waterproof/moisture vapor permeable inserts and raschel knit 8.0 $\pm$ 0.5 oz/yd^2 40% para-aramid/25% PBI/25% PFR rayon linings, with para-aramid wristlets.

Samples of the fabrics and gloves were sent to Biotherm, Inc. for testing in accordance with NFPA 1973-1988. Some interesting results were noted.

1. Flame Resistance

Flame Resistance testing noted no problem with afterglow with either the aluminized shell or the para-aramid wristlets. Biotherm results showed 0.0 inches char lengths, and 0.0 second afterflame and afterglow for leather, aluminized shell and wristlet, compared to a maximum requirement of 4.0 inches, 2.0 seconds and 8.0 seconds respectively. Consumption was 2.0% or less, compared to a 5% maximum. Discussions were held with Biotherm, ADL, and Hoescht-Celanese technicians in an effort to ascertain the reason for the marked difference with the Phase I results. A telephone interview was held with Mr. Cliff Haskell of

the Sacramento Fire Department (NFPA 1973 Subcommittee Chairman), regarding the opinions held at the time the standard was drafted. Mr. Haskell noted that the original intent was to not have the gloves continue to be consumed, and providing a source of ignition up the sleeve of the firefighter, after the gloves were removed from the flame. Examination of test samples confirmed that the only part of the fabric that glowed after removal from the flame was the aluminized polyester film. Placing a single layer of paper tissue immediately on the glowing area did not even scorch the tissue. Thus, it seems unlikely that the firefighter could be injured from this effect. To preclude problems in interlaboratory testing of the aluminized fabrics, the term "afterglow" was redefined in the fabric specification such that consumption of the base fabric would be required to disqualify the fabric.

2. Shrinkage

Heat Resistance testing did not note the shrinkage problem found in Phase I. When performed at Biotherm, the glove shrunk 0.7% in width and 1.1% in length, while the cuff shrunk 0.0% in width and 0.6% in length, compared to the 5% maximum requirement. It is assumed that utilizing the 105°C shrinkage requirement discussed above requires that the tanner supply leather with a higher chrome or lower fatliquor content. In any event, it appears that this should not represent a procurement problem.

3. Conductive Heat Tests

Conductive Heat Testing noted the marked change in the test method from NFPA 1973-1983. Biotherm noted a time to pain (TTP) of 17.5 seconds for dry and 11.7 seconds for wet samples, and time to burn (TTB) of 36.7 seconds for dry and 20.2 seconds for wet samples. These values far exceeded the requirement of 6.0 second TTP and 10 second TTB. The old version of the standard, using a higher exposure temperature of 940°F with a maximum skin limit of 111°F rather than 536°F with a 140°F skin exposure, was much more stringent. Members of the American Society of Testing and Materials (ASTM) D 4108 committee were contacted, who noted that the hotplate utilized could not reach temperature levels equivalent to the old version, which used a block of heated iron as a challenge.

4. Puncture Resistance

Initial Puncture Resistance tests performed by Biotherm resulted in values well below the 13.2 pound minimum requirement. Discussion regarding preconditioning noted that Biotherm had improperly preconditioned the samples by utilizing surfactant (detergent) in the wash and dry cycles required. This apparently softened the leather significantly. After proper preconditioning, Biotherm recorded dry values averaged 24.1 dry, and 13.3 pounds wet, compared to a 13.2 pound minimum requirement.

5. Grip Test

The Grip Test results showed little variation between baseline, wet and dry samples. Biotherm recorded equal or increased grip values compared to baseline for both wet and dry samples. It is possible that the silicone treatment added to the leather used in Phase II reduced the water absorption and

provided improved results. Again, further research on such treatments would beinteresting.

6. Dexterity Tests

The Dexterity Test results confirmed the limited field evaluation conducted on aircraft in Phase I. The 125% values measured by Biotherm exceeds the minimum requirement (<140%) by 15%. Evaluation of the gloves at ADL using the aircraft switch panel supplied by the Navy showed no difficulty in operating any switches, although the more complicated switches with covers required two hands to manipulate with wet gloves.

7. Cut Resistance

The Cut Resistance test results showed little variation from the Phase I results. Biotherm recorded 18 pounds for all samples tested from palm and back, whether wet or dry.

8. Water Penetration

The Water Penetration test performed at Biotherm produced failing values, based on pinhole leaks of the Bion II insert seams at 4 psi. This was very surprising, considering the excellent results (over 8 psi) measured at ADL in Phase I. ADL staff and the Navy COTR met with Emtex, Inc. the producer of the inserts, who stated that a change in the manufacturing procedure had taken place after the Phase I tests. Seams in current production inserts were being formed by heat sealing the coated face of one side of the insert to the uncoated faced of the other side. Retesting of both varieties of inserts at ADL confirmed that inserts bonded by heat sealing the two coated faces together reliably exceeded the 8 psi test value. Emtex agreed that a military production stock number would be established that would assure that inserts constructed in this manner would be utilized for any Navy procurements.

After performing the testing of these inserts without facing with leather and backing with lining fabric (as done in NFPA 1973) as a "worse-case" scenario, it was determined that testing under the Navy specification should also be done in this manner. However, to reduce stretching of the insert fabric at higher pressures, a lightweight nylon taffeta backing cloth will be incorporated in the specification.

As a comparison, the new insert available from W.L. Gore and Associates was also evaluated. This insert is constructed with a 30 x 15 denier nylon tricot knit laminated to a PTFE membrane. The Gore insert also passed the water resistance requirement easily, measuring 8 psi. Several gloves were constructed with Gore inserts and evaluate for dexterity. It appeared that the use of the heavier 30 x 15 denier tricot, as opposed to the 15 x 15 denier tricot used in the Bion II insert, did reduce dexterity, although the Gore insert gloves were not evaluated on the Bennett Dexterity Test. It was decided to specify the 15 x 15 denier nylon tricot base fabric in the specification to maximize dexterity. While moisture vapor transmission rates (MVTR) are not required by NFPA 1973, experience with coated gloves previously utilized by firefighters noted problems in drying gloves between shifts. Gloves with Gore-tex liners have not experienced this difficulty. Army testing demonstrated that a MVTR of 400

$g/m^2/24^{hr}$, when tested in accordance with American Society for Testing and Materials Standard E-96, method B was a reasonable value for many available materials (Truonh, J.Q., et.al., Testing and Evaluation of waterproof/Breathable Materials for Chemical Protective Clothing Applications, U.S. Army Natick RD & E Laboratory, 1987). It was decided to set this level as a minimum for the purchase specification.

9. Thermal Protective Performance

Thermal Protective Performance (TPP) test results also presented some problems. Since repeated TPP tests with dry samples were conducted in Phase I, only wet samples of the aluminized (glove back) composite were initially tested in Phase II. When a failing TPP value of 33.2 was recorded by Biotherm, additional testing was performed at the Hoescht-Celanese PBI Division Laboratory at Charlotte, N.C.. An average TPP of 39.6 was noted, well in excess of minimum requirements.

Experiments with various fabrics noted that the amount of water contained in the fabrics was critical to the test results when fabric rather than leather was used for the outer shells. The greater mass of the leather provides a much higher TPP, thus the differences caused by water in these samples was relatively insignificant. To determine the reason for the variations with the aluminized fabric, discussions were conducted with technicians at both laboratories. It was determined that Biotherm was using two pieces of blotting paper on each side of the sample when removing water during preconditioning, while Hoescht-Celanese used one piece, as specified in the NFPA 1973. Wet TPP testing was again performed at Hoescht-Celanese to confirm the previous results; an average value of 46.0 was recorded. After examining the results, the Navy COTR accepted the Hoescht-Celanese results, and decided to go ahead with the field testing.

10. Field Tests

Seventy-five pairs of gloves were placed in the field at both Navy and Air Force facilities. While complete results are not available at the time of this report, initial feedback indicated that significant improvement in dexterity of the experimental design glove over the previous crash fire/rescue gloves. Comments required a minor resizing of the patterns, reducing the finger length and fingertip width slightly to place the fingertips closer to the glove, thus enhancing tactility in this critical area. These changes will be incorporated into the final patterns delivered to the Navy.

In the gloves supplied to the field, Sharnet urethane hot-melt adhesive was used to fasten the fingertips of the lining to the insert. It was noted that this did not provide adequate bond strength in some instances. For this reason other adhesives were investigated. It was determined that silicone adhesive provides an adequate bond, but the application is critical to maintaining fingertip tactility. To provide required dexterity, the adhesive must be applied to the back of the fingertip only, using a small dot that is squeezed to a circle or oval that is approximately 0.75 inch in diameter. The adhesive must be allowed to dry to tack (at least 60 minutes and preferably overnight) before the glove is turned.

IV. DISCUSSION

A number of problems that occurred during the program caused significant delays.

The release of NFPA 1973-1988 was delayed longer than expected, thus work during most of Phase I could be done only with testing conducted in accordance with NFPA 1973-1983, or a draft of the revised standard that was not completely accurate.

The change in the standard that had the most impact on the program was the introduction of the Custom Scientific Instrument (CSI) Thermal Protective Performance tester for evaluating the performance of the glove in high radiant and convective heat flux conditions, with both wet and dry samples. While leather shells provide excellent performance in this area, fabric shells, even when aluminized, cannot provide as effective protection. Since aluminized shells were required to meet the even higher radiant heat flux encountered during hydrocarbon fuel fires, this was a problem if gloves with high dexterity were to be produced. It was interesting to note that slight variances in the amount of water added could either increase or decrease the TPP values. Discussions with Dr. Roger Barker of North Carolina State University indicate that the thermodynamics of water in the system are quite complex and could provide subjects for a number of doctoral studies. In any event, closely adhering to the test protocol did provide passing results for the glove composite utilized.

Testing for 100% radiant environments also presented a problem that had to be overcome. As noted previously, the CSI apparatus could not be used, as the flat orientation of the sample over the heat source (quartz lamps) caused the polyester film to char. Comparison with the Navy Crash Fire Simulator showed that vertical orientation in front of the heat source (again, quartz lamps) provided better results. However, it was noted that testing the aluminized fabric alone, as required in MIL-SPEC-C-24941, Cloth, Laminated, Aluminized (Para-aramid/PBI), produced very similar results. Because of this, it was decided to reference the test methods used to qualify fabric for this specification in the glove specification, so that fabric suppliers are not required to custom-build an apparatus equivalent to the Navy's.

Another problem area confronting the program was the development of aluminized fabric that would provide effective protection and still be flexible enough to allow adequate dexterity. Originally it was intended that aluminization would be done on KGI's 3M aluminization apparatus. However, it was apparent early in the program that KGI's process would not produce a fabric that could meet the Navy's requirements, although formerly the 3M product was acceptable. It is postulated that either 3M had utilized some in-house technique that was not passed on to KGI with the apparatus, or, that the polyester film utilized had degraded due to age. In any event, instead of having ready access to aluminized fabrics, fabrics had to be sent out to Gentex, Inc. for processing. While the Gentex process easily met Navy requirements, the time delay for each fabric treatment ranged from 6 to 12 weeks. Using a napped knit fabric with the Gentex film provided the combination of flexibility, thickness and radiant heat resistance that was required for the glove to meet Navy requirements.

The selection of a waterproof insert also was a complex problem. Initial work with the Gore-tex film was not promising; apparently the insert had insufficient mass to increase TPP values enough to meet the minimum 35.0 requirement. Substitution of the heavier, fabric reinforced Bion II insert increased the value significantly. It was anticipated that the introduction of a fabric reinforced Gore-tex insert would allow this product, which has had excellent results in structural firefighting gloves, to be utilized. It is surprising that Gore has been unable to duplicate the passing TPP values provided by the Bion II insert. It is postulated that the Bion II urethane melts during the test, absorbing heat, then releases it by solidifying after the measurement period is over, while the more heat resistant PTFE membrane may pass heat directly through. In any event, it is desirable for procurement purposes that an additional source of insert become available.

It was noted above that the Conductive Heat Resistance test utilized by NFPA 1973-1988 was discovered to be much less stringent than the test used in NFPA 1973-1983. The NFPA was notified of this by ADL and as a result, this test has been marked for examination during the next revision of the standard in 1992. Since there is not separate heat resistance or flame resistance test for linings in NFPA 1973, it is possible that thermoplastic materials such as polyester could be substituted for more protective materials. While it may be possible to get such a fabric to meet the NFPA 1973-1988 requirement, it is probable that the more stringent heat exposures that are found in the field, particularly at hydrocarbon fuel fires, would cause it to melt, severely burning the firefighter. For this reason, a separate flame resistance test will be specified in the navy specification for lining fabric.

The closing of the Avtex Fiber plant that produces PFR rayon also delayed the project, as PFR rayon had to be obtained by Hoescht-Celanese from Lenzing AG in Austria in order to produce fabric for Phase II. Again, this could be a problem for the Navy in final procurement. It is possible that another fiber, such as self-extinguishing flame resistant (SEF) modacrylic, could be substituted for the rayon in the blend, but further work would need to be performed to confirm this.

V. CONCLUSIONS

Although production of appropriate fabrics and development of manufacturing techniques was not a trivial task, it was determined that production of a glove meeting Navy requirements for crash fire/rescue operations and NFPA requirements for structural fire fighting could be done using state-of-the-art technology.

TABLE I

Time to Burn Index (TBI) and Thermal Protective Performance (TPP) of Glove Composites Exposed to Radiant Heat on CSI Apparatus

Sample	Fabrics	Flux (cal/cm^2/sec)	TBI (sec)	TPP (TBI/Flux)	Notes
A.	Alum PK(G)				charred
	PTFE				melted
	PKD	1.8	36.0	20.0	discolored
B.	Alum PK(G)				
	PKD	1.8	27.0	15.0	discolored
C.	Alum PKD(3m)				v. charred
	PTFE				melted
	PKD	1.9	22.0	11.6	charred
D.	Alum Kev(3m)				v. charred
	PTFE				melted
	PKD	1.9	24.0	12.6	charred

Alum - aluminized
PK(G) - PBI/Kevlar knit, Gentex process, 5 oz/yd^2
PTFE - Goretex film
PKD - PBI/Kevlar/Durvil knit, 3M process, 8 oz/yd^2
Kev (3M) - Kevlar knit, 3M process, 8 oz/yd^2

TABLE II

Qualitative Tests of Aluminized Fabrics Exposed to 1.9 cal/cm^2/sec Radiant Flux on NCTRF Quality Control Apparatus

Sample	Time	Results	Notes
Alum Kev (3m)	30	Fail	Blotter browned
	60	Fail	Blotter charred
Alum PKD (3m)	30	Fail	Blotter browned
Alum PK(G)	30	Pass	No change
	60	Pass	No change
	90	Fail	Blotter browned
	120	Fail	Blotter charred

Alum Kev - Kevlar knit, 3M process, 8 oz/yd^2
Alum PKD - PBI/Kevlar/Durvil knit, 3M process, 8 oz/yd^2
Alum PK - PBI/Kevlar woven ripstop, 8 oz/yd^2

TABLE III

Thermal Protective Performance Test Results

Shell	Moisture Barrier	Lining	TPP
Alum. Kevlar (8.0 oz/yd^2	Goretex	Kevlar (9.0 oz/yd^2)	42.4
Alum. Kevlar (8.0 oz/yd^2)	Goretex	PBI/Kevlar/Durvil (8.0 oz/yd^2)	33.0
Alum. PBI/Kevlar/Durvil (8.0 oz/yd^2)	Goretex	PBI/Kevlar/Durvil (8.0 oz/yd^2)	32.0

TABLE IV

Grip Test of Experimental Glove Models

Subject	Baseline/ Dry Halyard	Dry Gloves/ Dry Halyard	% Change
1	51.9 lbs.	40.5 lbs.	-22.0%
2	65.5 lbs.	61.5 lbs.	-6.1%
3	62.5 lbs.	41.5 lbs.	-33.6%

Subject	Baseline/ Wet Halyard	Dry Gloves/ Wet Halyard	% Change
1	68.0 lbs.	71.8 lbs.	5.6%
2	78.5 lbs.	77.5 lbs.	-1.3%
3	67.5 lbs.	59.5 lbs.	-11.9%

Subject	Dry Halyard/ Wet Glove	% Change from Baseline Dry Halyard	Wet Halyard/ Wet Glove	% Change From Baseline Wet Halyard
1	66.0 lbs.	27.2%	59.0 lbs.	-13.2%
2	79.0 lbs.	20.6%	81.5 lbs.	3.8%
3	56.5 lbs.	-9.6%	60.0 lbs.	11.1%